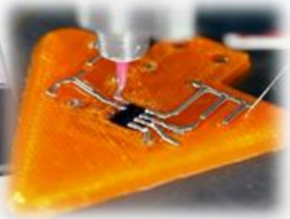
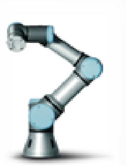
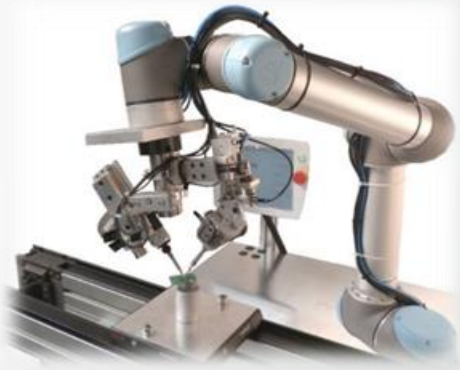
Overview of MSFC Additive Electronics Capabilities

ES43 – EEE Parts Packaging- Additive Electronics Laboratory

Focus: Marshall seeks to support the Agency in the development of next generation printed electronics technologies for living and working in space, with emphasis on enhanced electronics manufacturing processes and capabilities development on the ground and in-space







NEAR-TERM

- Human Habitation Elements and Life Support Systems-pursuing integrated flexible wearable air, water, vital monitoring solutions for next generation printed technologies
- Complete startup printing technology demonstrations which prove basic processes and establish ISM infrastructure needed for future applications including metals based manufacturing

MEDIUM-TERM

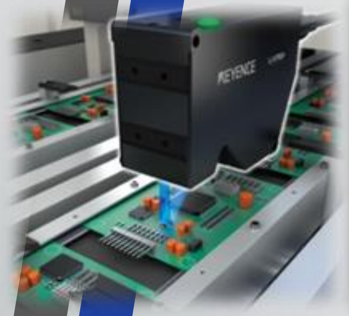
- Target low cost research and demonstration activities that support multi-material additive manufacturing, more sophisticated parts production, printed electronics and ISM
- Maturation and flight demonstration of printed propulsion system components, with emphasis on infusion into small spacecraft-based missions

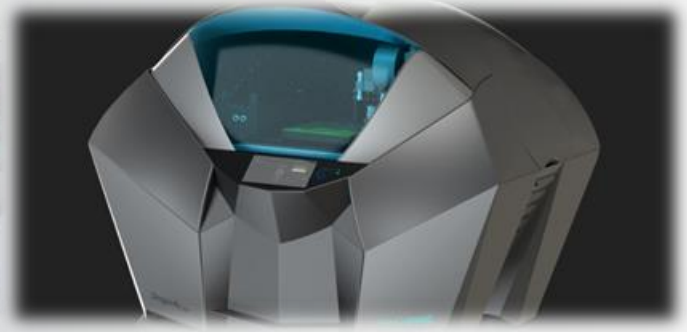
LONG-TERM

- Evolve systems capabilities to be supportive of destination (lunar or Mars) resources and requirements, increase autonomy in systems and utilize in-situ resources towards manufacturing
- Support development of self-replicable systems and their infusion into future spacecraft and missions

Overview of FY17 SBIR Subtopic for Printable Electronics

Focus: In-Space Printable Electronics: The purpose of this subtopic is to encourage highly collaborative research and development in the area of In-Space Printable Electronics capabilities geared towards laying the foundation and infrastructure for the next generation of in-space advanced electronics manufacturing technologies.





HARDWARE DEVELOPMENT

3D Electronics Manufacturing Hardware Miniaturization and Adaptation for Microgravity Environment

- Repackaging of commercially available 3D electronics printers for microgravity
- Addition of in-line metrology processes
- Integration of advance robotics and automation processes to facilitate assembly and repair
- Incorporation of open source flexible hardware architectures supportive of various printer platforms

SOFTWARE DEVELOPMENT

Advanced Software Development for use in Microgravity based 3D Electronics Printers and Manufacturing Systems

- Development of open-source flexible intuitive software environments that integrate multiple electronic printing methodologies
- Improving existing open-source software platforms to support advanced open electronics printer hardware configurations and architectures to support additional metrology solutions
- Introduction of advanced integrated design and manufacturing graphical user interfaces that support autonomy and tele-operations of 3D electronics printers and manufacturing systems

Phase 1 Objective: 3D electronic printer prototype development aimed at in-space production of passive electronic parts (non-semiconductor based)

Phase 2 Objective: Improve existing in-space electronics manufacturing capabilities to include higher complexity active electronic elements (semiconductor based components)

Phase 3 Objective: Continued development of advanced in-space electronics manufacturing infrastructure and introduction of self-supporting avionics manufacturing architectures and systems

Overview of In Space Manufacturing (ISM)

Why is this project important?

- *The operations & logistics approach utilized for ISS is not feasible for long-duration missions.
- ISM provides a "pioneering" approach which will help to enable sustainable, affordable Exploration mission operations and logistics.
- ISM is key to addressing significant logistics challenges for long-duration missions by reducing mass, providing flexible risk coverage, and enabling new capabilities that are required for Exploration missions.

Objectives

- Develop and enable the technologies and processes required to provide affordable, sustainable on-demand manufacturing, recycling, and repair during Exploration missions.

Current activities

- ISS Refabricator Tech Demo, NextSTEP FabLab contracts with Techshot Inc., Interlog Corp., Tethers Unlimited, Inc. (TUI), ISS AMF Ops, 3D Print Tech Demo Results, Printable Electronics Dev, 8 SBIRs underway, ISM Design Database Development with LSS, LR, and NextSTEP UTAS, Future Engineers STEM SAA, X-Hab Filament Development

ISS Additive Manufacturing Facility

ISS Refabricator

NextSTEP 'FabLab'

Printable Electronics:
LSS Pressure Switch (Left);
UV Radiation Sensor (Right)

Design Database Development
ISM LSS Retaining Plate (Left); LR Urine Funnels (Right)

* *Quantitative Benefit Analysis performed in 2016 for ISM Utilization study. The analysis used data from ISS maintenance and logistics tracking, as well as EMC Deep Space Habitat studies.*

Overview of FY18 Printed Electronics Objectives

Target Objectives

- Leverage innovative trends in Additive Manufacturing and Printed Electronics to build foundational knowledge and capability to support in-space manufacturing of Electronics
- Facilitate the translation of low TRL printed electronics research into high value ISM core products
- Expansion of government public/private sector partnerships with industry, academia, and society

FOUNDATIONAL KNOWLEDGE AND COMPETENCY DEVELOPMENT

FY17-18 nScrypt Characterization Plan development

FY17 Additive Manufacturing Technology Roadmap for Avionics and Electronics

MSFC Additive Electronics Laboratory Capabilities (Ground Capabilities)

Novel electrode design strategies to improve reliability of printed devices

Lessons-learned from first balloon flight of a printed radiation sensor to finalize sensor design

PUBLIC AND PRIVATE PARTNERSHIPS

FY17 Phase I SBIR: In Space Manufacturing (Printable Electronics)

- ✓ Optomec-(Adaptive Laser Sintering System (ALSS))
- ✓ Techshot-(Software and Tools for Electronics printing in space (STEPS))

FY18 Phase II SBIR: In Space Manufacturing (Printable Electronics)

- ☐ Techshot-(Software and Tools for Electronics printing in space (STEPS))

FY18 Phase I SBIR: Plasma Jet Printing Technology for Printable Electronics in Space

- ☐ Open Jan 11th-Mar 9th, 2018

FY18 NextSTEP Broad Agency Announcement: FAbLab

- Techshot, Inc
- Tethers Unlimited, Inc
- Interlog Corporation of Anaheim

FY18 ISM Printed Electronics Workshop

Apr 3rd-4th, 2018 Huntsville, AL

RESEARCH AND TECHNOLOGY DEVELOPMENT

FY17-18 ECLSS UPA Pressure Switch assessment and development

Development of Printable Universal Kit v2

Development of printable RFID Sensor for ECLSS

Printed Electroluminescent light panel development

All-printed triboelectric nanogenerator development

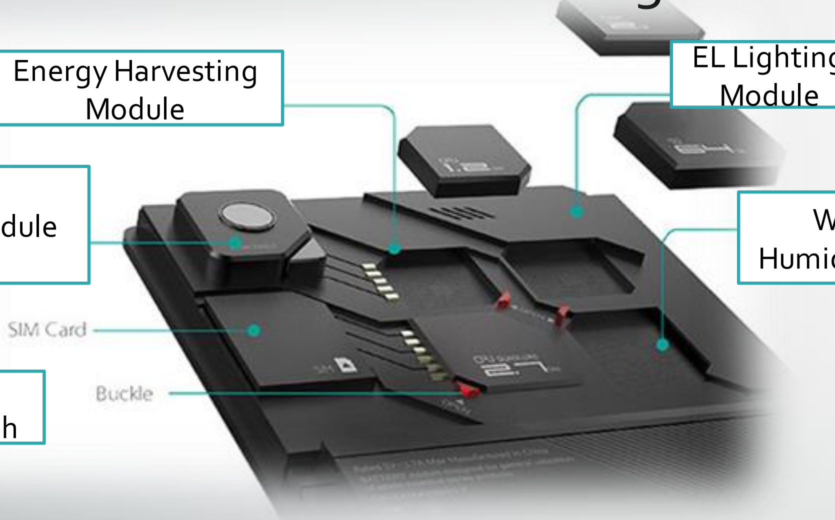
Printed prototype of resistive random access memory

Radiation sensor design

Deliverables for FY17 Efforts

- The **Purpose** of the FY18 printed electronics task is to utilize a collaborative inter-agency team approach to leverage emerging R&D technology trends and innovations in printed electronics, towards the development of next-generation electronics manufacturing capabilities in space.
- <u>This FY18 task meets NASA needs for developing sustainable technologies and maturing systems required for deep-space missions by identifying and pioneering new solutions to technical and human challenges.</u>

Printed Universal Kit with Demonstration Technologies onboard



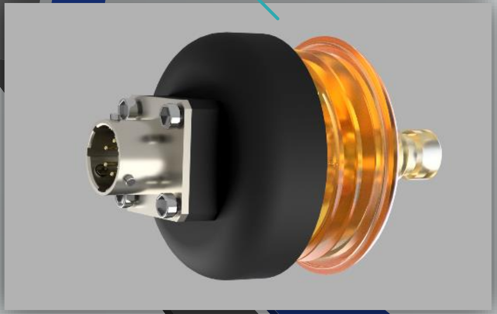
Energy Harvesting Module

EL Lighting Module

Sensing Module

Wireless Humidity Sensor

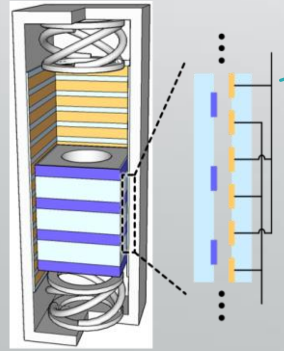
ECLSS UPA Pressure Switch



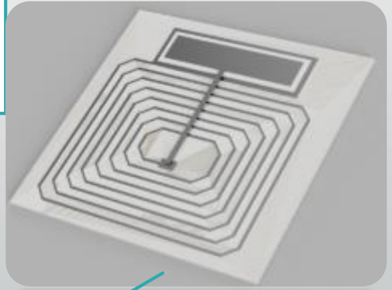
ISM Ground Technology Demonstration

- nScrypt printer characterization results for printed electronics capabilities
- ECLSS UPA Pressure Switch
- Tech Demo of printed Universal Kit v2
- Printed transistor & memory modules
- Updated ISM Additive Manufacturing Technology Roadmap for Avionics and Electronics

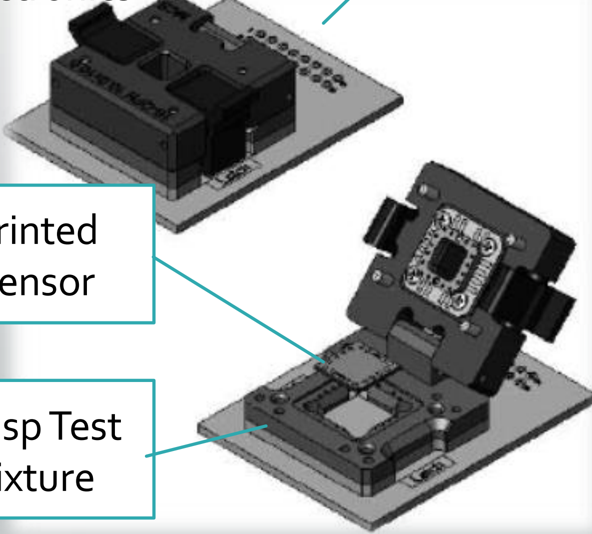
Universal Kit v1



Fully printed Triboelectric Nanogenerator



Printed Wireless Sensor Technology

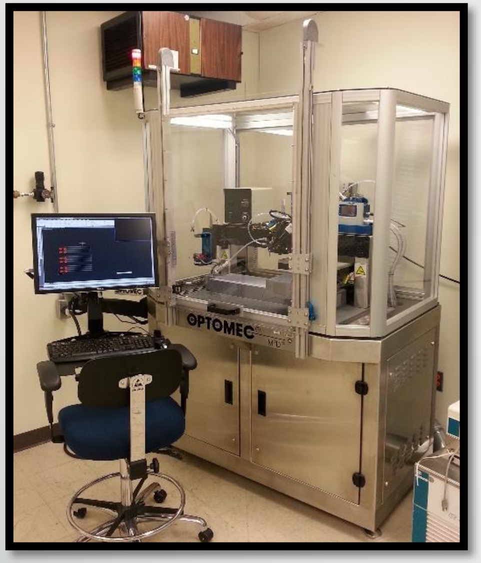


Printed Sensor

Clasp Test Fixture

EEE Parts Packaging Additive Electronics Laboratory

Optomec High Precision 3D Aerosol Jet Printer



Additive Electronics Manufacturing

Primary Focus: Utilizing 3D additive dispensing, screen printing, and aerosol jet deposition processes to develop nanoelectronics including but not limited to:

- **Solid State Ultracapacitors**
- **Graphene Superconducting Circuitry**
- **Organic Photovoltaics & LEDs**
- **Electroluminescent Devices**
- **Sensors**
- **PCBs**
- Antennas
- 3D Flexible Interconnects for Area Array Packaging
- Embedded Electronics Packaging
- Advanced Electronic Manufacturing

HMI 485 High Precision Screen & Stencil Printer

Hengli Custom 8-Zone HT Sintering Furnace

Hengli Custom 4-Zone LT Sintering Furnace

Silverson L5M-A Laboratory Mixer

PVA 350 Tabletop Robotic Dispensing System

ES43/EM41 Nano-Electronic Materials Processing & Furnace Lab

Silverson L5M-A Laboratory Mixer

Torrey Hills Ceramic 3 Roll Mill

Sonics Corp 75 & 10 Watt Ultrasonic Probes

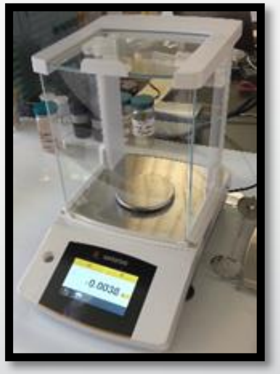
Microtrac Nanoparticle Size Analyzer

Lindberg Vertical Fluidized Bed Furnace

Primary Focus: Supply Additive Electronics Lab with a range of custom, ready-to-print nanoelectronic inks (to be printed using Aerosol Jet, Dispensing, and Screen Printing processes)

- Treated Ceramic Nano-Inks
- Highly Capacitive Dielectric Inks for Ultracapacitor Research
- Graphene Superconductor Inks
- Metal Nanoparticle inks (Ag, Au, Cu, Al, NI)
- Semiconductor nanoparticle inks
- Polymer & Acrylic based Ink vehicles/binders

Sartorius Analytical Balance



Hengli Tube Furnace

Torrey Hills Metal 3 Roll Mill

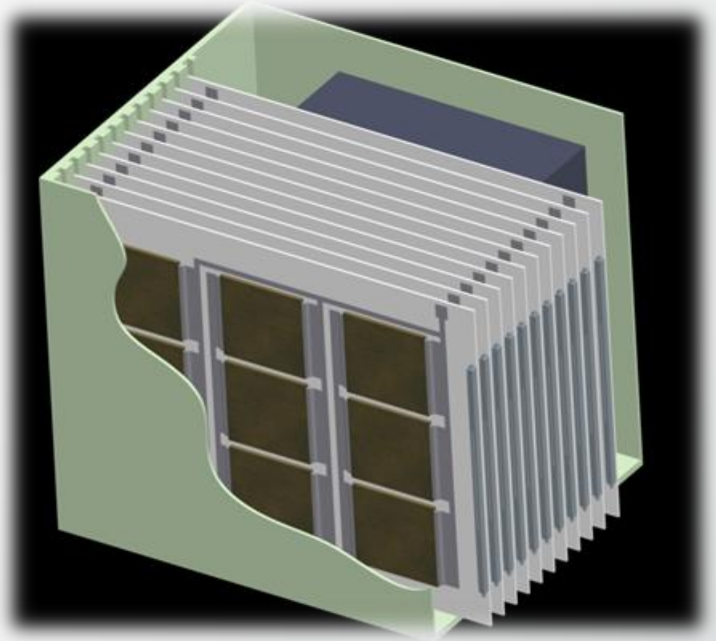
US Stoneware Ball Mill

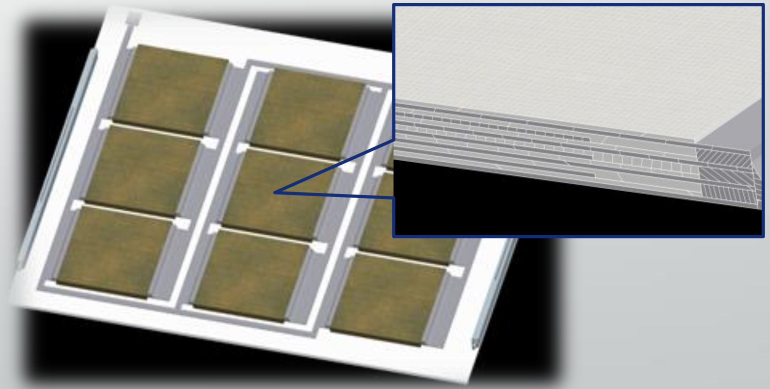
Sweco Vibratory Mill

Electronics R&D (solid-state Capacitor)

Motivation: To eliminate hazards associated with electrolytic energy storage devices such as lithium ion and replace NASA's Range Safety Battery

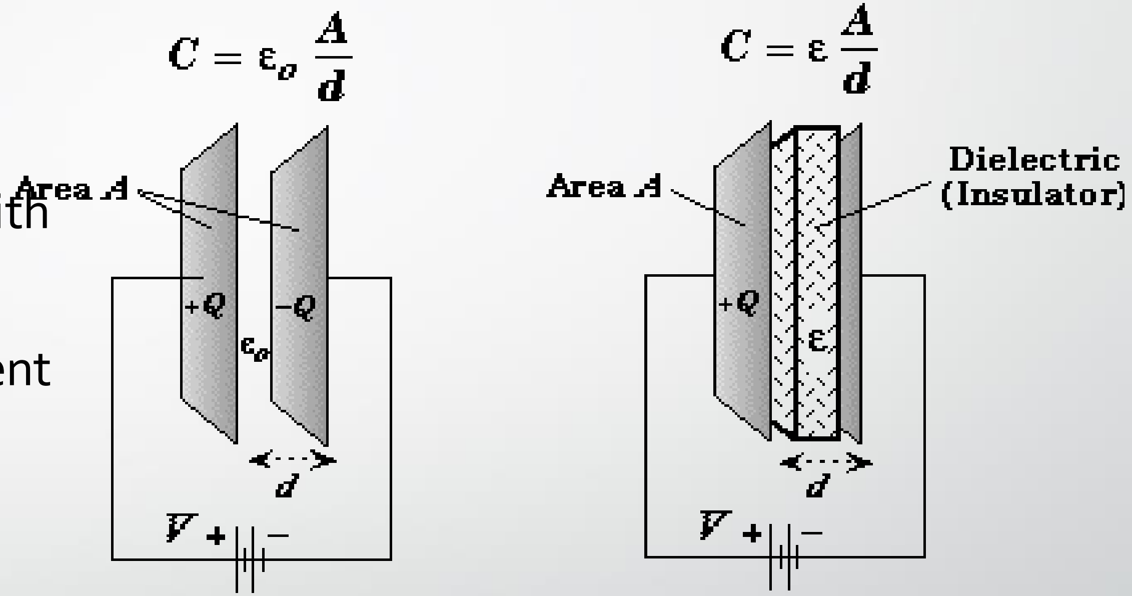
- Significant interest in solid-state ultracapacitors for battery replacement, in-space electric propulsion systems, and mass reduction of space power systems
- Terrestrial applications of this technology are numerous and broad including but not limited to: electric vehicles, directed energy weapons, grid leveling, solar energy capture, residential power, hand tools, and portable electronics

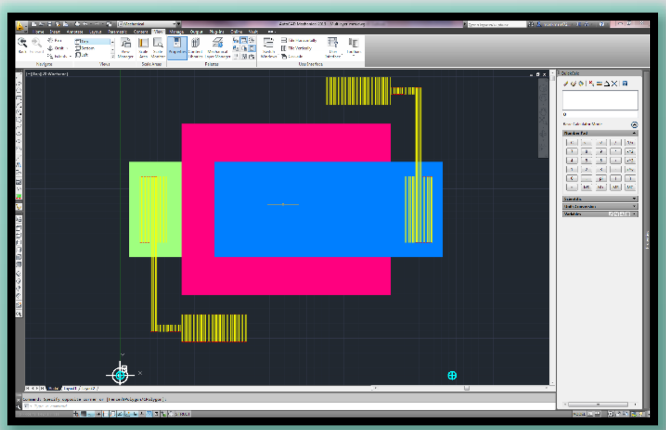




Electronic Design
(Parallel plate capacitor)

- Aerosol printing integrates the design and manufacturing environment
- Multi-layer and multi-material device design with emphasis on layer thickness
- New opportunities to innovate within component packaging and interconnection schemes
- Significant increases in speed from design to manufacturing
- Electronic design process entails additional understanding of material selection and behavior



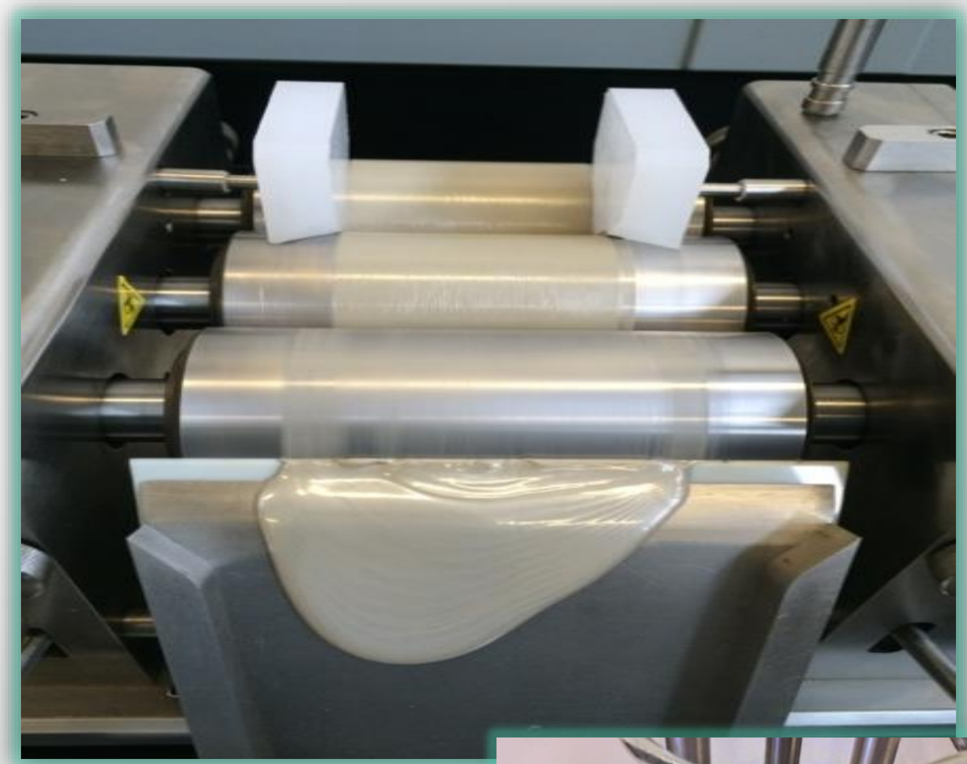


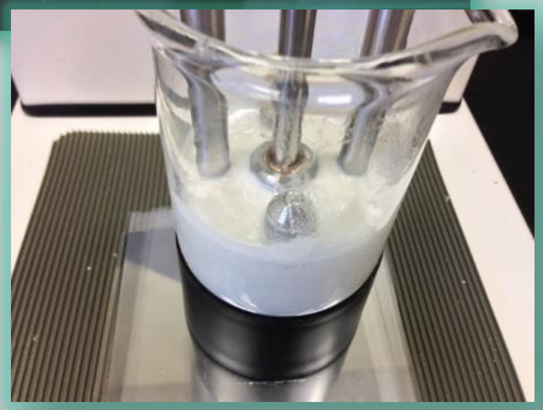
Material Development (Ink Formulation)

Importance of developing our own materials capability

- Custom treatment of dielectric materials to tune properties
- Maximize permittivity (capacitance) and voltage for ultracapicitors
- Mill particles to sizes appropriate for 3D printing
- Optimize processing capabilities (% solids, viscosity)

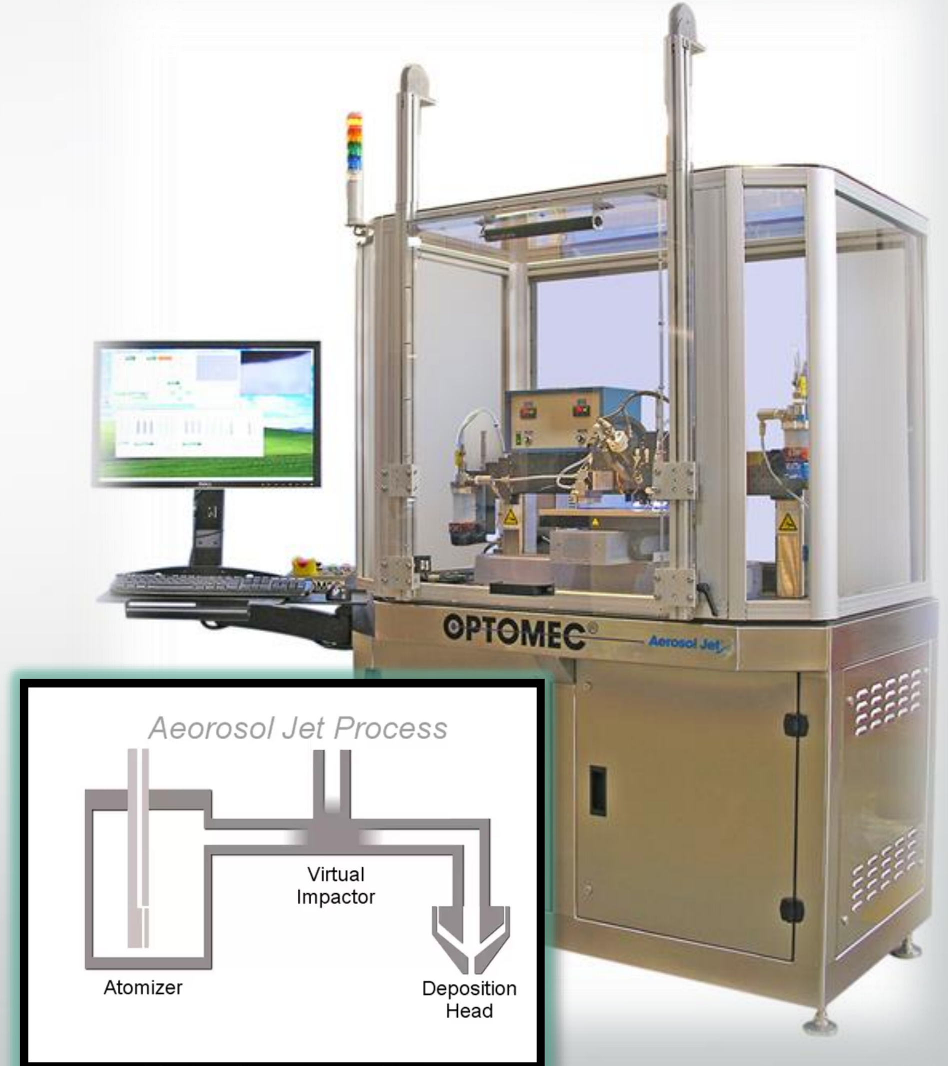
- Lack of good commercially available 3D materials
  - Need for developing our own conductor inks
  - Ensure industry supply is available
  - Optimize properties lacking in commercial inks such as: conductivity, substrate adhesion, solderability





3DPrinting
(Aerosol Jet Deposition)

- Standard export/import file transfer structure with the option to add customized programming to the file
- Raw print material is loaded in the form of an ink with specific physical properties compatible with the machines atomizers and nozzles
- Simulation and thorough parameter adjustments are available to achieve maximum desired material output and coverage
- Multi-layer devices like the Ultracap require precise alignment setup due to intermediate processing of differing layers of material
- Complete cleaning and inspection of pneumatic systems between material loads provide for best results
- Increased scalability through design or by programming



The deposition system consists of an Atomizer, Virtual Impactor, and Deposition head

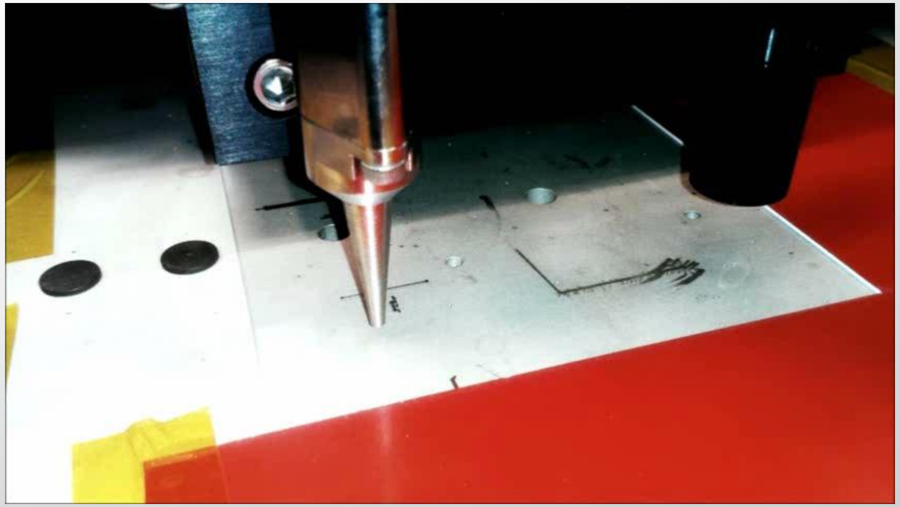
Printing the Ultracapacitor

PRINTING THE LAYERS

- Following Ink formulation test printing and parameter adjustments maximize quality
- The substrate material is aligned with platen using fiducial system
- The bottom electrode layer is deposited first then cured
- Secondly the dielectric layer then cured
- Finally the top electrode layer with final curing step

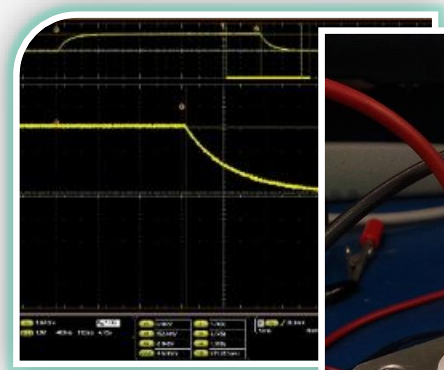
CURING THE LAYERS

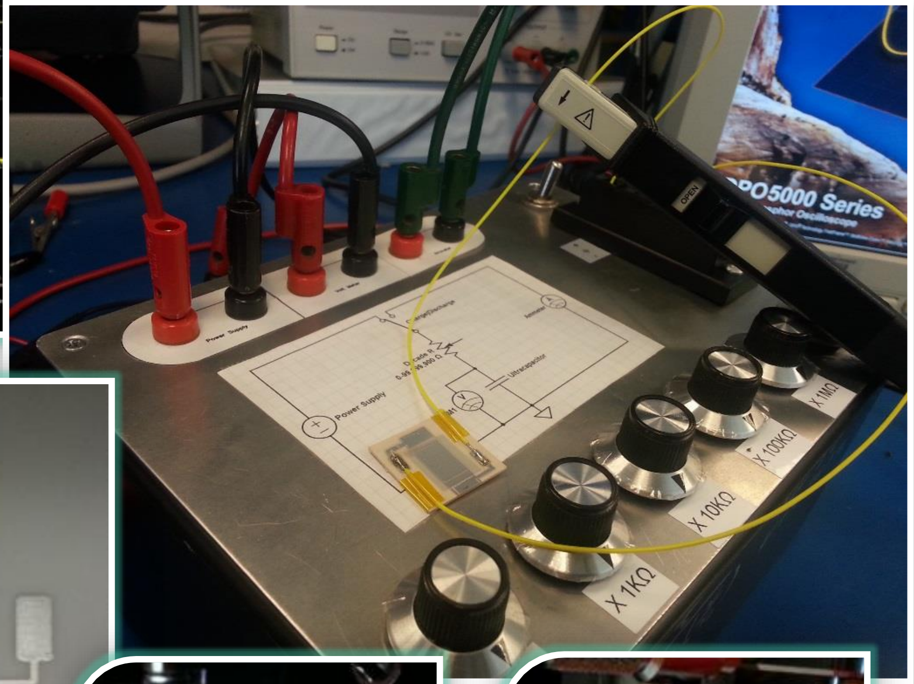
- Custom sintering methods available
- Material specific 3 zone curing profiles
- Nitrogen Dry box for clean room temp drying and protection
- High and low temperature atmosphere controlled applications

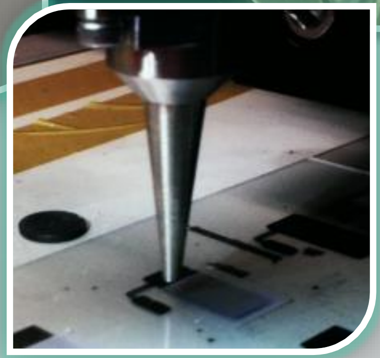


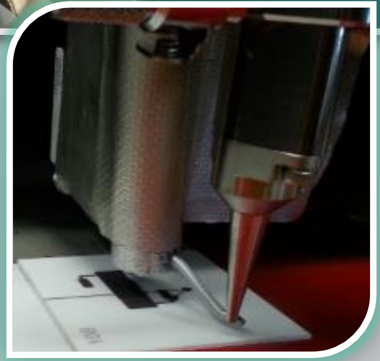
Device Testing (In-circuit Testing)

- In circuit testing approach for capacitor charge and discharge behavior
- Allows us to focus on desirable electronic characteristics with emphasis on material changes
- Sheds light on printing problems and helps determine in what ways the printing techniques affect the electrical properties of the devices
- Helps to measure the repeatability of the printing process overall by monitoring the consistency in the electrical test results of the devices
- Provides feedback for adjustments in material development process
- Proves to be a total metric of how successful the process and how useable the device will be









Alternative Applications

Packaging and Assembly

- High Density Interconnects – 3DIC
- Flip-Chip / Direct Die Attach
- Embedded / Integrated Passives
- Flex Circuits

Electronic Components

- Resistors, Capacitors and Inductors
- Micro-Antennae
- Micro-Batteries

Electronic Devices

- Flat Panel Displays
- Fuel Cells
- Micro-Sensors
- MEMS & RFID
- Solar Cells

Hybrid Manufacture

- Smart Structures

BioTech

- Bio-Sensors
- Implantable Devices
- Micro-Arrays